The team

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The problem

- Conceive an imaging system with low dimensionality measurement for efficient search of the hypothesis space as to answer the "20 questions" for a task at hand. Optimize:
  - Efficiency of search
  - Reliability of each decision
  - Overall probability of success

The problem is hard because…

- It is a general ATR problem where detailed image information is aggregated into a few measurements early on. This data reduction, if not done correctly, may limit the ability for repetitive and adaptive search.
  - Detect (e.g., saliency, features)
  - Recognize (e.g., models, templates)
  - Track (e.g., low-latency, localized processing, attention)

The Concept: the What

- Missionized Imaging: optimal extraction of task-specific information. Optimize:
  - photon efficiency, speed, data load (communications + processing)
  - form factor, weight, power, …
- Extract information: answer relevant “question” at each time increment.
- Imaging becomes the process of making measurements to facilitate a search in hypothesis space
  - optimal search (shortest time) requires access to specific measurements
  - realize these measurements with optics/electronics: what is optimal optics/electronics decomposition?

The What (cont'd)

- Optics is efficient for linear transformations/projections (static 4D).
- Electronics is efficient at nonlinear, logical, search, machine learning, local and temporal operations.
- Search process requires adaptation of optics and electronics to get the right questions answered.
- Key Issues:
  - Make relatively few measurements at each epoch -> SNR increase + data reduction
  - Select best questions at each epoch: fast and reliable decisions.
  - Must adapt optical/electronic transformation in response to decisions

Some "how" issues

- Sometimes a few measurements are sufficient to decide problem (task specific):
  - e.g., iris recognition requires 5 features … measure basis directly.
- Sometimes the null space is known or discovered early:
  - e.g., only illuminate through canopy openings
- Sometimes invariances are known a priori (task specific):
  - e.g., ring-wedge detectors
- Decompose desired measurements into optics + electronics. Challenges:
  - are useful measurements decomposable ?
  - how to achieve decomposition ?
  - how to exploit arrays: more photons, spatial (and other) diversity

Additional Notes

- Adaptation is cost so problem domain may be defined by fixed features… suboptimal
  - e.g., conventional imaging is example
- Adaptation may also be achieved by over deployment in array
  - e.g., a separate sensor for every question
- Active illumination = both time and space variant
  - e.g., two-pulse ladar, structured illumination

Optical Processing

- Methods of optical projection: volume holography, custom/adaptive refractives, inteferometric, active illumination, obscurations (reference structures)
  - challenges: how to make these adaptive/flexible/programmable?
  - how to optimize photon usage?
  - can flexibility be limited to planes?

Detector Plane Processing

- Nonlinear data aggregation, e.g.
  - Voting/search/selection/WTA, Histogram analysis, max/min/median, sorting, higher order moments… (other global/local signal descriptors).
- Low-latency decisions and feedback
  - Information-theoretic streaming of incremental decisions.
  - The most informative bit of information comes out of the sensor first.
- Temporal processing,
  - Event detections, Timestamps, heterodyne detection…
- Quantization, communication.
- Novel signal utilization strategies for increased SNR, Dynamic Range, measurement prioritization, …

DARPA Questions

- What are we we trying to do? Extract task-specific information
- How is it done now? Image formation generally precedes image processing and trends are toward ever-increasing sensor resolution.
- What are limitations? Photon efficiency, data load (communications, latency, processing, …), payload issues,
- What is new that removes limitations and improves performance? Realization that optical transformations can improve the efficiency of sensor.
- Why now? Unmanagable data loads, demonstrated non-traditional imaging, adaptive sensing facilitates agile information extraction,
- Why can it work?
- What is not known? Implementation of tunable optical transformations, theory of optimal constrained search, optimal decomposition, how to balance analog v digital signal conditioning/processing/computing
- If successful what difference will it make? Enables network-centric warfare: improves photon efficiency, manage data load, reduces latency => improving timeliness and reliability of decisions.

Illustrative Example

- Airborne surveillance and target detection.
  - Compute saliency map (iterate through a few adaptation cycles to find out what makes most robust signatures, optical signal selection, polarimetric/phase/spectral bands)
  - Localize the most interesting spots.
  - Interrogate interesting spots by:
    - Adapting the system
    - Invoke another or our sensory better suited for task.